Analysis on Mechanical Properties of Waste High Density Polyethylene (HDPE) Plastic

by

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22695

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical)

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CERTIFICATION OF APPROVAL

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Approved by,

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(Dr. Othman Mamat)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2020

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

NUR ATIKAH BINTI YUSA’

ABSTRACT

High Density Polyethylene (HDPE) has been widely used in industrial and commercial products nowadays because of its material. HDPE has outstanding tensile strength and it also has high-impact resistance and melting point. There is no doubt plastic is very useful. Despite that, the problem from plastic is that most of it is not biodegradable and it takes hundred years to rot. This study aim to reduce solid waste from HDPE plastic by using recycling and reuse method and could save resources and raw material for future generations. The objective of this research is to analyse and compare the mechanical properties of HDPE waste and compare it with standard HDPE. Nonetheless, there is still not much analysis of the mechanical properties of recycled HDPE as there is not much information on the materials. This study provides evidence of lower mechanical properties of recycled HDPE compared to pure HDPE by using tensile and hardness test. Hence, all findings suggest that recycled HDPE to add another fiber to strengthen its bonding

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LIST OF ABBREVIATIONS

HDPE	High Density Polyethylene
LDPE	Low Density Polyethylene
PE	Polyethylene
UTM	Universal Tensile Machine
UTS	Ultimate Tensile Stress
ASTM	American Society for Testing and Materials
WP	Wood Powder

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Plastics have becoming a major part of our modern way of life, and over the past 50 years the global production of plastics has risen tremendously. This has made a significant contribution to plastic-related waste production. Besides, plastic has been commonly used in a wide range of products due to its favorable properties, including high toughness, low density, ease of design and manufacturing, high strength-to-weight ratio and low cost. Currently, polymer type plastic products are widely used in almost every industry, especially in the areas of packaging, construction and infrastructure, automotive, electrical and electronics, agriculture as well as other sectors [1].

High Density Polyethylene (HDPE) have become popular polymer that has been widely used in industrial and commercial products nowadays because of its characteristics. HDPE has outstanding tensile strength and it also has high-impact resistance and melting point. HDPE also is a thermoplastic type which means that it can be melted and repeatedly reshaped to a solid-state. It is made by combining ethylene molecules (thus "poly" "ethylene") primarily extracted from U.S. natural gas supplies. We can classify HDPE by looking at number 2 printed in our daily bottle, surrounded by a chasing arrow.

Due to the many benefits from HDPE plastics, its production has been increased greatly during the last decade and more than half of that amount was wasted on one-off disposable consumer products, which greatly contributed to plastic-related waste production. Moreover, such forms of plastics are non-biodegradable and chemically unreactive; thus, such polymer products have not decomposed for decades, even centuries. As a result, plastic waste is widely considered a serious environmental problem. Since it is impossible to avoid plastic use, which in parallel with the development of new technologies, the problems arising from the increasing use of plastics, particularly HDPE plastics, need to be searched for realistic solutions.

For this purpose, a study on waste HDPE, is carried out in order to know its mechanical and chemical properties. The mechanical and chemical properties of this material will be studied and discussed in further chapters.

1.2 Problem Statement

Polyethylene thermoplastics are already widely recognized in various industries such as automotive, household and food packaging. There is no doubt plastic is very useful. Despite that, the problem from plastic is that most of it is not biodegradable and it takes hundred years to rot. This is due to the intermolecular bonds that constitute plastics that ensure the structure to not corrode of decompose. Experts believe that the amount of plastic in ocean is going to weight more that the amount of fish in the ocean by year 2050. Attempts were made to recycle and reuse back HDPE plastic in order to reduce the environmental impact. Nonetheless, there is still not much analysis of the mechanical properties of recycled HDPE as there is not much information on the materials [2]. Hence, author's made a decision to study recycle HDPE plastic.

1.3 Objective

The objectives of this project were:

1. To determine the mechanical properties of waste HDPE using Universal Testing Machine (UTM) and hardness test machine.
2. To compare and analyze the mechanical properties of waste HDPE and standard HDPE.

1.4 Scope of Study

This project will focus to design a mould that have a dog-bone shape, which is the form of testing specimen following ASTM 638. Next, waste high density polyethylene (HDPE) will be tested its mechanical and chemical properties using UTM and DSC machine. Tensile tests were done to examine the tensile strength of these waste HDPE. The tensile test result of each type of waste were tabulated then compared with the standard HDPE. Hardness analysis will be conducted using durometer shore hardness machine following UTP's standard operating procedure for hardness testing as references to perform the experiment. The location if this research was conducted at laboratory of Mechanical Engineering Department in UTP.

CHAPTER 2

LITERATURE REVIEW

2.1 Polyethylene (PE)

The world's most popular plastic is polyethylene (PE). This polymer is a multifunction material as it can create food containers, shampoo bottles, kid’s toys, and even use in kitchen utensils. It has the simplest of all commercial polymers, a very simple structure. Polymers are high molar mass substances in their molecules and consist of a significant number of rep-eating units. There is nothing more than a long chain of carbon atoms in a polyethylene molecule connected to each carbon atom by two hydrogen atoms as shown in Figure 1. There are polymers that are both natural and synthetic. Proteins, starches, cellulose and latex are among the naturally occurring polymers.

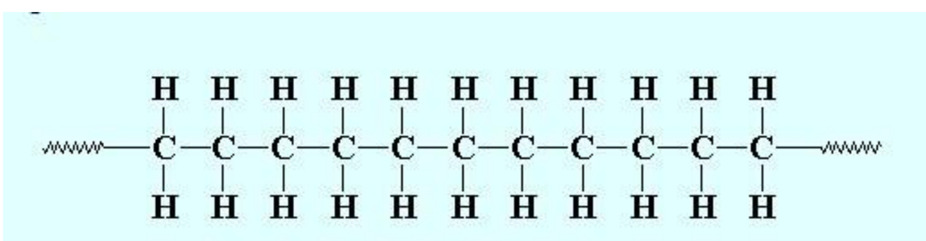


Figure 1: HDPE Structure [2]

Also known as a "thermoplastic," polyethylene and the name is related to the material's heat response. Thermoplastic products will become liquid at some point of melting. A great useful feature of thermoplastics is that they can be warmed, cooled, and heated to their melting point without any degradation and moulded again to reuse it.

Polyethylene is made from ethylene gas. Ethylene gas is derived by products from the cracking of natural gas 5 feedstock or petroleum [3]. Ethylene is still a gas at this stage and requires stress and a catalyst to convert it into a resin called polyethylene as shown in Figure 2. The process used to produce polyethylene from ethylene is called polymerization. Ethylene usually polymerizes under broad range of stresses, temperatures and catalysts (depending on the type of PE) to form very long polymer chains. Different technique will produce different types of PE resins. The ability to produce so many varieties of a raw material makes it possible for the manufacturer to modify PE resins for different applications

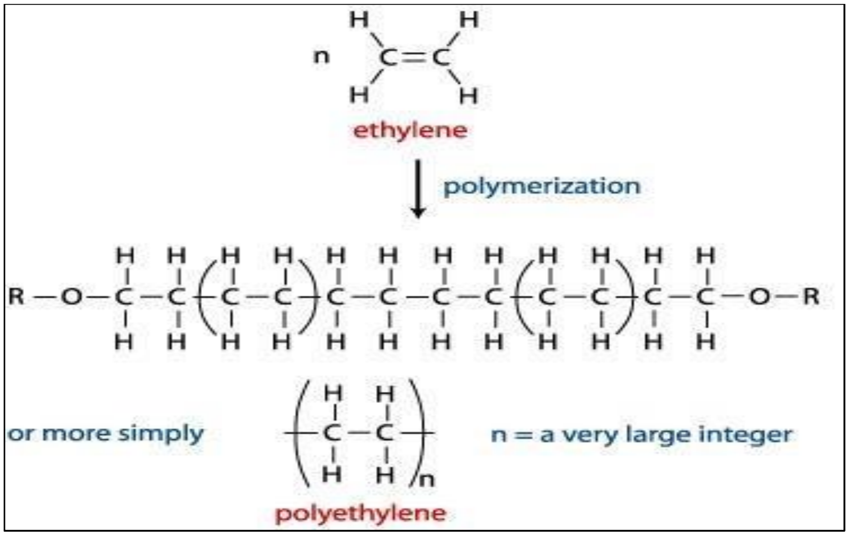


Figure 2: The Polymerizarion of Ethyle to Produce Polyethylene [2]

There are various kinds of PE such as low density polyethylene (LDPE) and high density polyethylene (HDPE). Figure 3 shows LDPE has shorter and many branching compare to HDPE. Produced by free-radical polymerization, in its crystal form, the branching comprises tightly packed molecular chains, so that LDPE has less tensile strength but more ductility [3]. This remarkable "formability" makes LDPE extremely useful for a variety of applications, from sturdy objects such as plastic bottles, detergents and bowls to non-sturdy ones such as trash bags.

On the opposite side of the polymer chain, HDPE has minimal branching of polymer chains. Less branching means that during crystallization the linear molecules are packed together which makes HDPE even more compact and rigid.

Besides, it also improves intermolecular strength hence result in higher tensile strength compared to LDPE. As HDPE has a tougher structure, it is often used as a plastic to produce detergent bottle, pipes, and garbage bins. Lesser branches in its structure will enables the polymer chains to attach tightly together. This will lead to strong-strength structure of HDPE that can withstand repeated exposure at 120 ° C and a melting point above 20 ° C compared to LDPE.

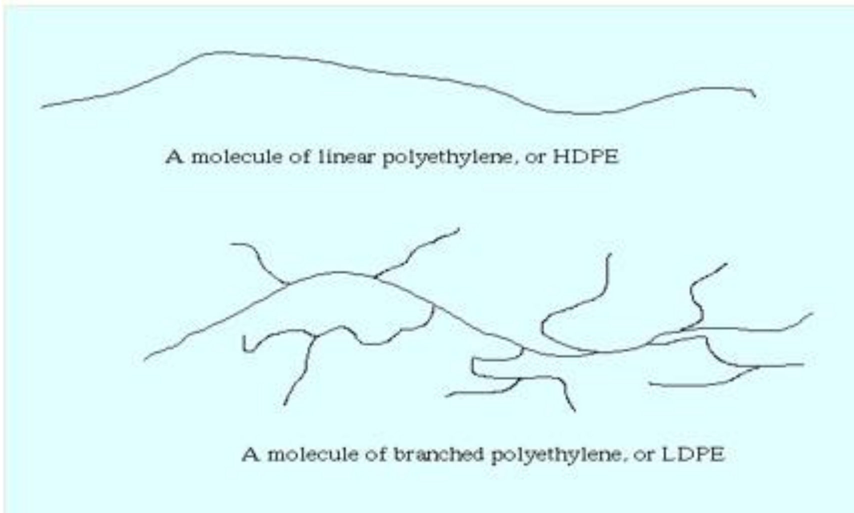


Figure 3: HDPE VS LDPE Structure [2]

2.2 High Density Polyethylene (HDPE)

High density polyethylene is a resin whose monomer is ethylene, also abbreviated as HDPE. It is a thermoplastic with a density ratio of very high strength. HDPE is a highly versatile material with a wide range of applications, from tubes to bottles for storage [4]. The melting point of high-density polyethylene is relatively high compared to other plastics. HDPE is the most popular type of polyethylene plastic which makes up more than 34 percent of the global plastics market. This polymer consisting of a large number of repeating units (known as monomers), and can be generalize the chemical formula as $(C2H4)_n$. The branching is relatively low in high-density polyethylene (as opposed to other polyethylene categories). The general HDPE structure is shown below.

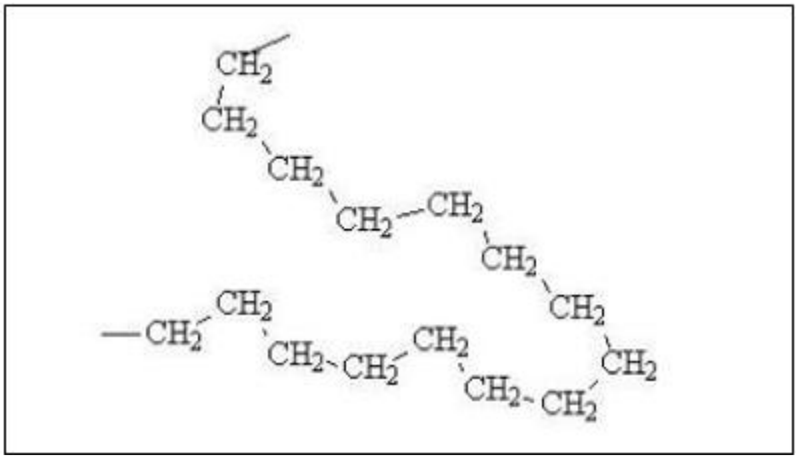


Figure 4: HDPE Structure [2]

In addition, HDPE is a hydrocarbon polymer, which can be made from ethylene through a catalytic reaction. Some of the popular catalysts used here are catalysts for Ziegler – Natta, catalysts for chromium / silica (Phillips catalyst), and catalysts for metallocene. Such catalysts typically attract free radicals in the polymerization phase at the end of the through polyethylene molecules. At the end of the molecules, they also add new ethylene monomers to form a long linear chain.

Table 1: HDPE Thermophysical Properties [5]

Mechanical Properties	Units
Density	940 kg/m^3
Melting Point	130.8 °C
Temperature of Crystallization	111.9 °C
Latent Heat of Fusion	178.6 kJ/kg
Thermal Conductivity	0.44 W/m. °C at °C
Specific Heat Capacity	1330 to 2400 J/kg-K
Specific Heat (Solid)	1.9 kJ/kg. °C
Crystallinity	60%

2.3 Mechanical Properties

2.3.1 Tensile Test

By using tensile test, mechanical properties of material can be determine. It is conducted by applying uniaxial load along the axis of a specimen until it deformed. Once a specimen is pulled beyond its ultimate tensile strength (UTS), a specific cross-sectional will starts to decrease. It is also known as necking deformation where the specimen experience greatest stress at this stage. With continued loading, necking deformation will keep increasing and finally split the specimen into two pieces.

Nevertheless, for tensile testing, the specimen shapes must be acceptable for standardization, in compliance with ASTM D638. Figure 6 shows the stress-strain nature of every plastic polymers and several useful properties of the material can be determine from the curve.

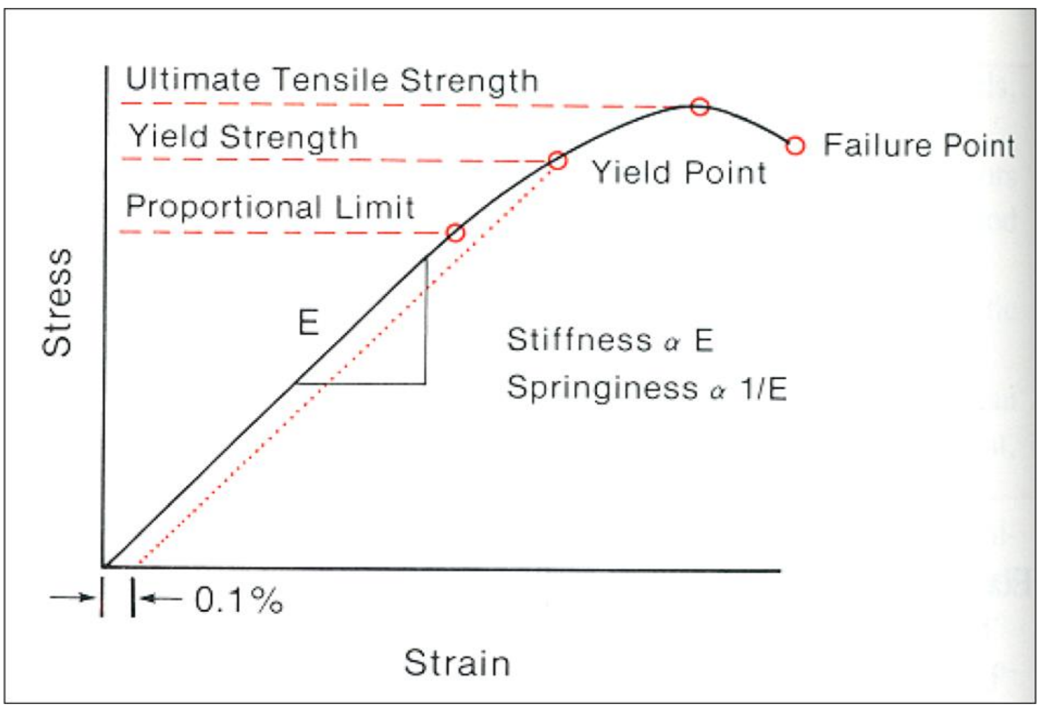


Figure 5: Stress -Strain Curve [6]

The details shown in Figure 6 for some characteristics are explained as follows:

1. Fracture point: Specimen reaches its limit of stretching and breaks into two parts.

2. Elastic region: A point before the specimen reach its yield point where the load is removed, the material returns to its original state.

3. Yield point: Represents material's elastic limit. In another word represents the end of elastic nature and the beginning of plastic nature. By removing the specimen before its yield point, the material can return to its original form.

4. Plastic region: A stage after the specimen reach its yield point of the material and the material will not be able to return to its original shape.

5. Ductility: A measure of how much pressure the specimen of material can put on before splitting into two. Even so, material with low ductility will simply break once it has been deformed, which also known as brittle material.

6. Young's Modulus: Also known as tensile modulus to measure elastic stiffness. It is an interpretation of reading the ratio of uniaxial stress to uniaxial stress in the range of stress in which Hooke's Law holds. Have to occur before the specimen reach its Yield point.

$$E = \frac{\Delta Stress}{\Delta Strain} \qquad \text{Eq. 1}$$

7. Resilience: Material's capability to retain energy when elastic region is deformed, and let go that energy when unloaded. Whereas, resilience modulus is describe as the energy limit that can be absorbed with no degradation per unit volume. By integrating the stress-strain curve from null to elastic max, it can be measured. Resilience.

$$U_r = \frac{\sigma_y^2}{2E} \qquad \text{Eq. 2}$$

8. Toughness: It's the amount of energy a substance will consume per volume before rupture to measure the region underneath stress-strain curve.

$$\frac{Volume}{Energy} = \int_0^{E_f} \sigma \, dE \qquad \text{Eq. 3}$$

By using tensile test, tensile strength of the material can also be determine. Tensile strength refers to how much stress the material can hold before it rips into two pieces. The specimen will undergo a stretch and elongation until it splits.

HDPE's tensile strength is usually between 3,000 and 3,500 pounds per square inch (psi), which in SI unit is approximately 20 to 32 MPa [7]. This also enables it to handle the transport of high pressure substances and to be easily manufactured into shapes without the risk of damaging the structure of the materials. The range of mechanical properties of HDPE is shown in Table 2

Table 2: Tensile Test Range for HDPE [8]

Quantity	Value	Unit
Young's modulus	600 - 1400	MPa
Shear modulus	700 - 800	MPa
Tensile strength	20 - 32	MPa
Elongation	180 - 1000	%
Fatigue	18 - 20	MPa
Bending strength	20 - 45	MPa

Mechanical properties of HDPE from ASTM D638:

Table 3: Tensile Yield Stress based on ASTM D638

Material	**Test Speed in./ min**	**Average (psi)**
HDPE	2	4101
HDPE	2	3523

Table 4: Tensile Yield Elongation based on ASTM D638

Material	**Test Speed in./ min**	**Average (psi)**
HDPE	2	9.27
HDPE	2	9.63

2.3.2 Hardness Testing

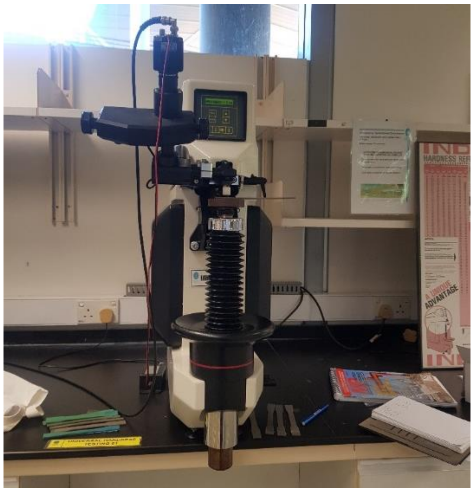


Figure 6: UTP’s Hardness Testing Machine

Hardness testing are used to know the resistance of a material to enduring indentation. The most common testing to measured hardness is Rockwell and Shore (durometer) hardness test. It is also can measured plastics and rubbers durability. For a hard material such as steel, acetal and polycarbonate, Rockwell hardness is usually being used. Meanwhile, Shore durometer is more common for softer materials types such as soft polymers, elastomers, and rubbers.

Nevertheless, the depth of the indentation will not be based on the hardness of the material only but also on its viscoelastic properties, indenter form and test frequency. Various shore-hardness tests are used to measure the hardness of different materials. Shore A and Shore D are the most widely used Scales. Shore A scale is used for 'softer' rubbers and plastics whereas Shore D scale is used for 'solid' rubbers and plastics.

In contrast, Rockwell hardness are measured by using different loads and size steel balls. The most common scales used for plastic are Rockwell E, M, and R and other Rockwell hardness scales are used for metals. The relationship between the various Rockwell scales used for plastics is very weak and the conversion between the scales is therefore discouraged.

CHAPTER 3

METHODOLOGY

This chapter will cover the process flow diagram of HDPE waste and standard HDPE. The focus will then change to the mechanical property testing, tensile test, SEM analysis, the project timeline with the key milestones in the form of Gantt chart is also shown in this chapter with comprises of the first and second part of final year project.

3.1 Materials Used

3.1.1 High Density Polyethylene (HDPE) Plastic

High-density polyethylene (HDPE) is a lightweight, super-strong material that is widely used in household items such as detergent and milk bottle. The HDPE bottles will be labelled as shown in Figure 7. HDPE bottles such as shampoo bottles and drinking water were recycle and processes into pellet. For this project, HDPE bottles will be collected at nearby waste. Mineral bottle cap, detergent bottle and milk jug are used to test the material properties.

Figure 7: Symbol Used in Recycling Waste of Plastics for HDPE [9]

Figure 8: Mineral Bottle Cup

Figure 9: Milk Bottle

3.1.2 **Granulator Machine**

Figure 10: Granulator Machine

A plastic granulator is a size reduction tool, an essential step in the recycling of plastics. The ability of plastic granulators to break down plastic products such as plastic bottles, containers, barrels and films into small, uniform parts called "regrinds". This may be the only step needed in some cases before it can be recycled in the production of new plastic products. Nonetheless, for the most part, plastic scrap recycling requires much more effort in processing and filtering, minimizing volume, washing, and pelletizing.

In a plastic granulator, an electric motor clamps cutting knives on an open rotor spun at high speeds. This rotor is located in a chamber where stationary knives are installed. As the plastic scrap enters this room, the rotating knives come in contact with the stationary knives, which slice the plastic into small pieces. At the bottom is a large screen with many gaps. The plastic must continue to be blended and sliced by the knives until it falls through this window small enough.

3.1.3 **Injection Molding Machine**

Figure 11: UTP’s Injection Molding Machine

Injection molding is a commonly used method for making anything from plastic products. To check the mechanical properties, injection molding machine is used for this project to create a dog bone shape from plastic pelletizing.

3.1.4 **Tensile Test Machine**

Figure 12: UTP’s Tensile Test Machine

Tensile or stress testing is one of the basic mechanical tests conducted on a material which is conducted by applying pressure on the material and measuring the material's reaction to the forces applied to it. The pull applied on the material leads to the elongation of the surface. The material's pressure and elongation will be measured, and data will be obtained. If the material is no longer able to withstand the stress it causes failure or extreme deformation.

The stress-strain curve were obtain using this tensile test. The results of the tensile analysis provide details on the mechanical properties of the material. Pulling the material before breakage helps to get the material's entire tensile characteristic. The values of the yield stress, tensile strength and elongation at break were also be displayed at the end of the experiment.

The breakpoint is the ultimate strength of the object, or what is called UTS. The resulting graph also shows UTS for the material. Analysis of the material under the force of elongation by stress-- graphs reveals several material characteristics and helps predict the material behavior. Tensile testing is carried out using ASTM D638, a standard test method for polymer plastic tensile properties.

Tensile Test Procedure

1) The product is cut or inserted into a "dog bone" shape below 14 mm thickness.
2) The specimen was load into tensile grips.
3) The test was begin by separating the tensile grips at a constant rate of speed.
4) The speed was set up 50mm per minute.
5) Time taken for the specimen to break was taken which is from 30 seconds to 5 minutes.

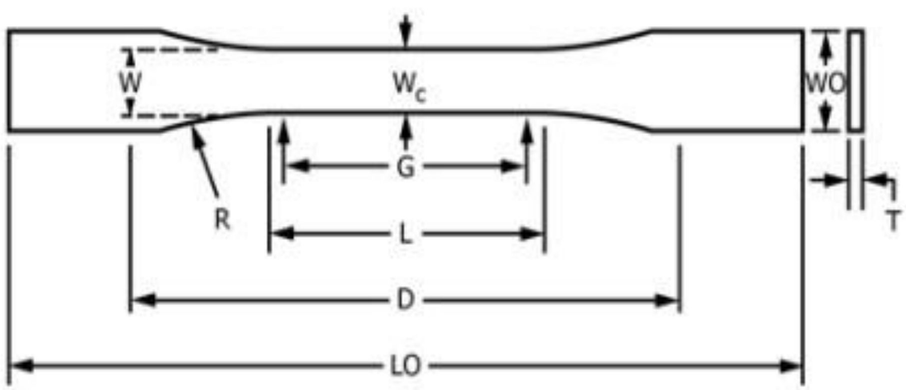


Figure 13: Dog Bone Shape and Dimension for Types I, II, III & IV from ASTM D638

Table 5: Specimen Dimension for Thickness, T, mm (in.) Based on ASTM D638

Dimensions (see drawings)	7 (0.28) or under		Over 7 to 14 (0.28 to 0.55), incl	4 (0.16) or under		Tolerances
	Type I	Type II	Type III	Type IV[B]	Type V[C,D]	
W—Width of narrow section[E,F]	13 (0.50)	6 (0.25)	19 (0.75)	6 (0.25)	3.18 (0.125)	±0.5 (±0.02)[B,C]
L—Length of narrow section	57 (2.25)	57 (2.25)	57 (2.25)	33 (1.30)	9.53 (0.375)	±0.5 (±0.02)[C]
WO—Width overall, min[G]	19 (0.75)	19 (0.75)	29 (1.13)	19 (0.75)	...	+ 6.4 (+ 0.25)
WO—Width overall, min[G]	...	...	...	...	9.53 (0.375)	+ 3.18 (+ 0.125)
LO—Length overall, min[H]	165 (6.5)	183 (7.2)	246 (9.7)	115 (4.5)	63.5 (2.5)	no max (no max)
G—Gage length[I]	50 (2.00)	50 (2.00)	50 (2.00)	...	7.62 (0.300)	±0.25 (±0.010)[C]
G—Gage length[I]	...	...	...	25 (1.00)	...	±0.13 (±0.005)
D—Distance between grips	115 (4.5)	135 (5.3)	115 (4.5)	65 (2.5)[J]	25.4 (1.0)	±5 (±0.2)
R—Radius of fillet	76 (3.00)	76 (3.00)	76 (3.00)	14 (0.56)	12.7 (0.5)	±1 (±0.04)[C]
RO—Outer radius (Type IV)	...	...	...	25 (1.00)	...	±1 (±0.04)

3.1.5 **Hardness Testing**

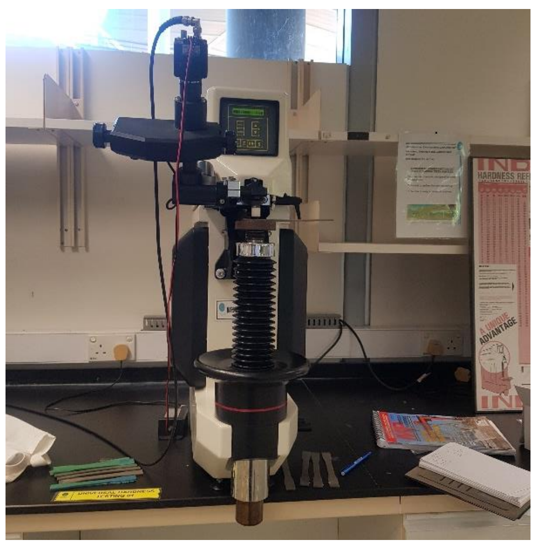


Figure 14: UTP's INDECTEC Hardness Testing Machine

Make sure the machine is in a good condition and safety first before operate the machine.

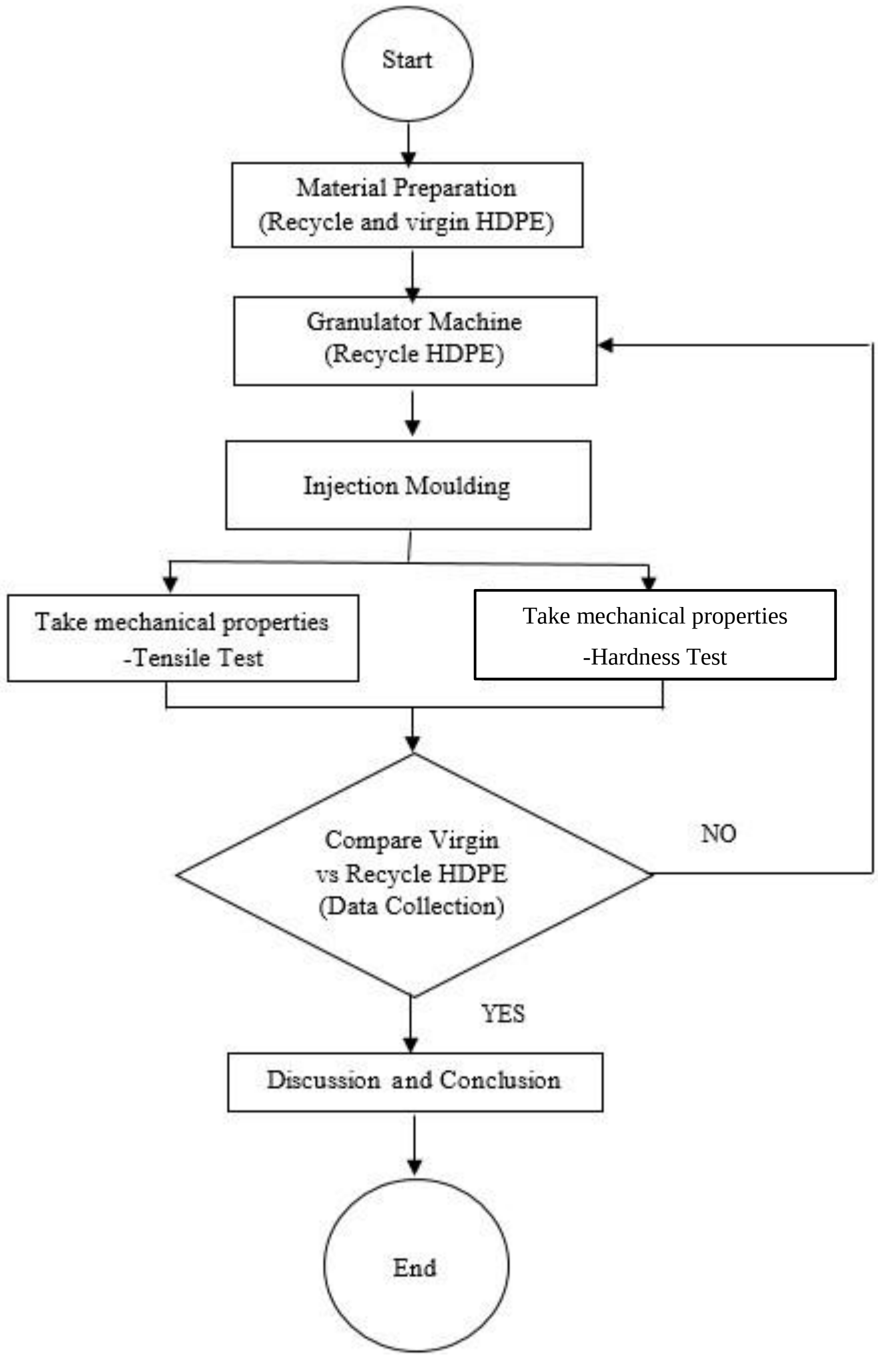
Rockwell Test Procedure:

1. The power supply was turned on and the indenter was advance to its forward position (nearest to operator)
2. The specimen was raised until the specimen surface touch the indenter tip.

3. The pre-load was applied to contact with the indenter while the hand wheel is turning in clockwise direction
4. Bleep sound are heard when the indenter’s vertical movement reached its limit and hardness number will be displayed.
5. Hardness reading was recorded.
6. The specimen was release by turning the hand wheel counterclockwise
7. Change to difference spot for next reading.

3.2 Experiment Process

This is an experiment process that need to be done to compare mechanical properties of recycle HDPE and pure HDPE.



3.3 Gantt Chart FYP 1

Table 5 shows gantt chart for fyp 1 from the beginning of the semester till the end of the semester.

Table 6: Activities and Milestones in executing the FYP1

Task	**Week**													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Confirmation of FYP title														
Research														
Identification of problem statement and objectives														
Literature review on HDPE Plastic						▲			●					
Preparation of proposal defence presentation								●	▲					
Project Planning/Methodology														
Collection of required materials for experiment - HDPE Plastic from several things e.g. cap mineral bottle, detergent bottle, milk bottle														●
Equipment and lab booking - To check on availability of required equipment											▲			
Preparation of interim report														▲

Legends:

Project Milestone	●
FYP Milestone	▲
Process	

3.4 Gantt Chart FYP

This is a gantt chart for semester 2. Basically it shows is an experiment process that need to be done within the schedule.

Table 7: Activities and Milestones in executing the FYP2

Task	**Week**													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Collection of sample														
Research														
Analysis on mechanical properties													●	
Submission of progress assessment 1						▲								
Submission of draft dissertation									▲					
Submission of draft dissertation (soft bound)										▲				
Viva												▲		
Submission of progress assessment 2												▲		
Submission of project dissertation (hard bound)														▲
Project Planning/Methodology														
Conduct sample on granulator machine			●											
Conduct sample on injection moulding machine				●										
Perform mechanical test for tensile									●					
Perform mechanical test for hardness												●		

Legends:

Project Milestone	●
FYP Milestone	▲
Process	

3.5 Research Progress

Table 7 shows research progress of experiment by percentage from the beginning till the end of the experiment.

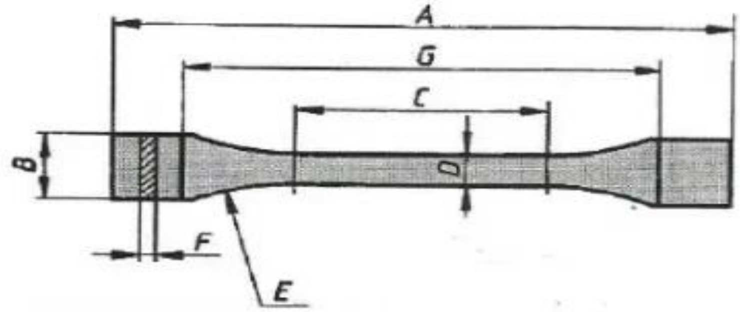
Table 8: Progress Experiment by Percentage

	Date		**ACTIVITIES**	**Percentage (%)**
	Start	**ENDS**		
PROJECT MILESTONE	20 Nov	06 Dec	Completion of material gathering	10%
	13 Jan	21 Jan	Conduct sample on granulator machine	10%
	22 Jan	29 Jan	Conduct sample on injection moulding machine	15%
	4 Feb	5 March	Perform mechanical test using UTM	15%
	11 Feb	23 Mar	Perform mechanical test using durometer hardness machine	5%
	12 Feb	21 March	Analysis of mechanical properties on tensile test	15%
	12 Feb	21 March	Analysis of mechanical properties on hardness	30%
			Total	100%

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Results for Tensile Test



Specimen parameter was determine by using a Vernier caliper as shown in Figure 20. A mean value was taken of three measurements.

Table 9: Measurement of Specimen From ASTM D638

Type of Specimen	HDPE
A	164 mm
B	19 mm
C	50 mm
D	13 mm
F	3.2 mm
G	57 mm

**Measurement E is not taken due to the lack of radius gauge*

For the measurement of stress, strain and Young Modulus, E of specimens the formula applies as follows:

Stress = $\frac{Force\ (N)}{Area\ (m^2)}$ Eq. 4

Area = Length (m) x Thickness (m) of the specimen Eq. 5

Strain = $\frac{Tensile\ extension\ (m)}{Original\ length\ of\ specimen\ (m)}$ Eq. 6

Young Modulus, E = $\frac{\Delta Stress}{\Delta Strain}$ Eq. 7

Specimen 1: High Density Polyethylene (HDPE)

Five specimens were tested under condition of 50mm/min for the speed of testing and the average is taken.

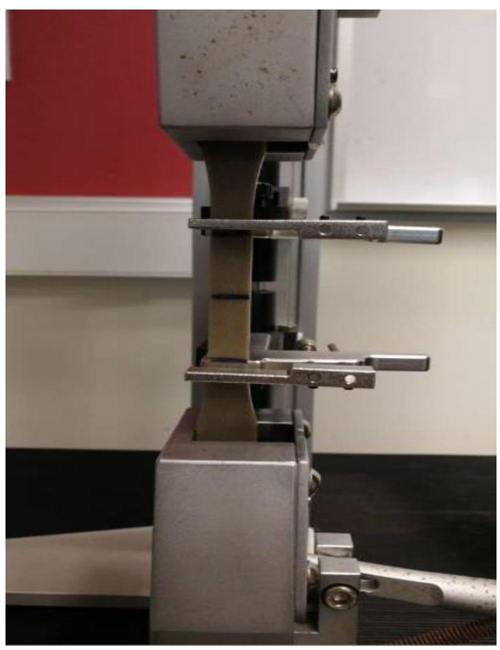


Figure 15: Specimen Undergo Tensile Test

The cross-sectional area and initial specimen length are measured as below:

Area = 0.013 m x 0.0032 m = 4.16×10^{-5} m^2

Initial length of specimen = 0.057 m

Stress and strain data calculated for HDPE:

Table 10: Results for HDPE Tensile Test

Test No.	Thickness	Width	Max. Load	Elastic Modulus	T.Strength	Yield Load	Yield strength	Elongation@Break
	mm	mm	N	MPa	MPa	N	MPa	mm
1	3.220	12.75	1054	1365	25.67	644.053	15.688	187.07
2	3.250	12.75	1085	1606	26.18	671.958	16.216	207.79
3	3.230	12.75	1084	1311	26.31	717.656	17.426	104.77
4	3.250	12.75	1103	962	26.61	676.703	16.331	99.14
5	3.260	12.75	1132	21714	27.23	794.696	19.119	95.88
Average	3.242	12.75	1092	5392	26.40	701.013	16.956	138.93
SD(N-1)	0.016	0.00	29	9127	0.57	58.594	1.364	54.00

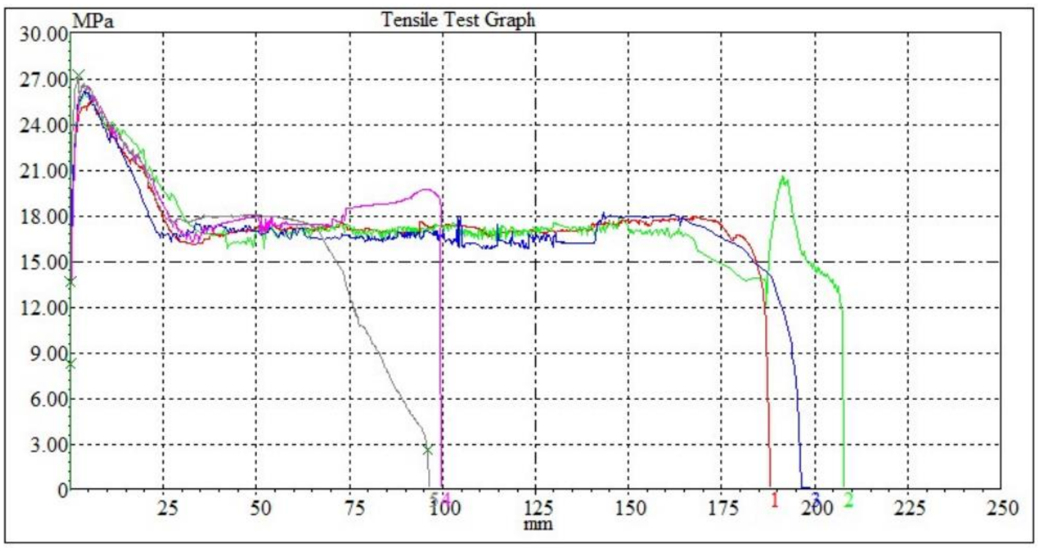


Figure 16: Stress - Strain Curve Obtained From The Experiment

From the Figure 22 the following averages can be determined:

i. Ultimate Tensile Strength (UTS) = 26.40 MPa
ii. Yield strength = 16.96 MPa (with 0.002 offset)
iii. Young Modulus, E = 5392 MPa

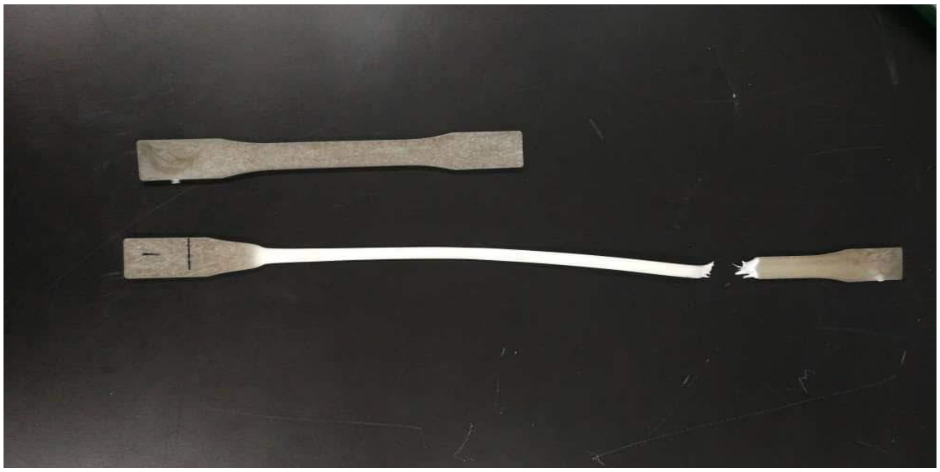


Figure 17: Specimen Before and After Undergoing Tensile Test

Above result stated that the average of Young Modulus is 5392 MPa whereas the pure HDPE are around 0.565 to 1.50 GPa which means the recycle HDPE is stiffer than the pure one. However, UTS for recycle HDPE is much lower than the pure which is 0.0264 GPa compare to the pure HDPE (7.60 to 43.0 GPa). The cause of a low UTS from recycle HDPE may affected from the main chain scissions accompanied by decrease in the molecular weight which came from the possible degradation through the recycling process. [1].

By approximation, plot from the engineering stress-strain in Fig.21 plot of each specimen, the yield strength for average recycle HDPE is 16.956 MPa. It is quite lower than the pure HDPE which is around 23.0 to 29.5 MPa. According to Alzerreca M., Paris. M, [10] molecular weight produce from the recycle HDPE in lower than pure HDPE and recycling method often generate chain scission, branching and crosslinking, resulting from various reactions involving free radicals. Which also mean degradation of the polymer chains caused during the formulation of the recycle can cause quality problems at extrusion for finished models hence results in lower yield strength.

Table 11: Mechanical Properties for Pure HDPE at 23 °C [11]

PROPERTY	UNIT	VALUE / RANGE
Tensile Strength, Yield at 23 C	MPa	23.0 - 29.5
Tensile Strength, Break at 23 C	MPa	30.5 - 33
Elongation, Yield	%	9 - 18
Elongation, Break	%	600 - 1350
Tensile Modulus at 23 C	MPa	900 - 1550
Flexural Strength, Yield	MPa	
Flexural Modulus	MPa	970- 1380
Compressive Strength	MPa	
Izod Notched	J/m (kJ/m^2)	71 - 159 (20)
Izod Unnotched	J/m	No Break

Elongation for recycle HDPE = $\frac{(138.96-35)}{35} x\ 100 = 297\%$

*Percent Elongation - The strain at fracture in tension and measure of ductility.

Based on Table 10, the elongation at break of pure HDPE are around 600 to 1350 percent and the elongation for recycle HDPE is 297%. According to Pattanakul and Selke, the higher the percentage of the recycled HDPE, the lower the elongation percent at break will be compared to the pure HDPE. Miltz and Narkis and Ram et al, they found that the mechanical property most affected by deterioration was elongation at break [6]. Therefore the results of this analysis are identical to their findings

Overall, recycled HDPE is a material with useful properties that are not substantially different from virgin resin ones. When recycling increases, more of this material will be available at a lower prices compare to the pure HDPE resin. Manufacturers may contribute to reduce the country's solid waste crisis by using this recycled plastic. In Dikobe and Luyt study, they stated that Young's modulus will increase and the stress at break will decrease with increasing wood powder (WP) content [12]. Hence, to increase the mechanical properties of HDPE, we can add another composite material to strengthen its bond.

4.2 Hardness Test Result

Figure 18: Specimen Used to Take HDPE Recycle Hardness After Indented

The laboratory procedures and the relevant specimens usually meet appropriate ASTM requirements. The laboratory's emphasis was simply to learn the testing methodology and to determine how the reported hardness data closely matched the final hardness values

Table 12: Thermo-Physical Properties for HDPE [13]

PROPERTY	UNIT	VALUE / RANGE
Melting Point	°C	126 - 135
Density	g mL^{-1}	0.955 - 0.961
Coefficient of Thermal Expansion x 10^{-5}	cm / (cm °C)	12.5 - 18.0
Heat Deflection Temperature, 0.5 MPa	°C	64 - 77
Heat Deflection Temperature, 1.8 MPa annealed (unannealed)	°C	76.5 - 78
Thermal Conductivity	W / mK	0.35 - 0.49
Shore Hardness, D Scale	n/a	55 - 67

Figure 19: Hardness Reading For Recycle HDPE

Figure 28 illustrates the variation of the Shore D Durometer hardness for the recycle HDPE. Based on the Figure 26 the virgin HDPE exhibited a Shore D Durometer hardness around 55 to 67, whereas the recycle HDPE had a Durometer hardness of 41.4 to 43.6 only.

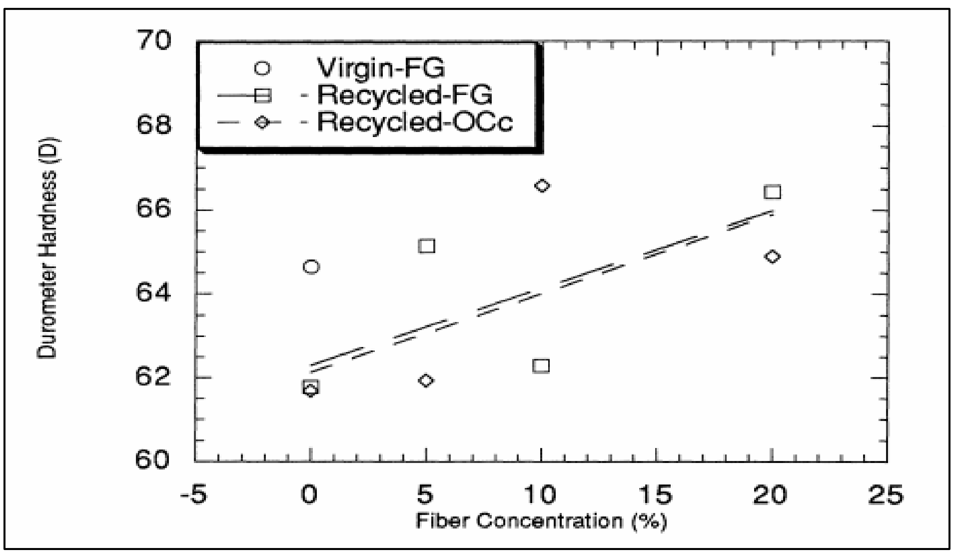


Figure 20: Variation of Shore D Durometer hardness of HDPE composites reinforced with FG or OCc fibers [14]

Based on Figure 28, hardness of the recycle HDPE can be increase by reinforced it with others reinforcement. The hardness tests seemed to demonstrate a basic trend that an increase in fiber content generally increased the hardness.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, after run all the experiments and make a comparison between recycle HDPE and virgin HDPE, author's manage to conclude that mechanical properties of recycle HDPE is much lower that virgin HDPE. At the beginning of the tensile test, the specimen exhibit a linear relationship between stress applied and elongation hence result in stress-strain curve when forces is applied. It is observed from tensile and hardness test that mechanical properties from waste HDPE are low than pure. The average of Young Modulus is 5392 MPa whereas the pure HDPE are around 0.565 to 1.50 GPa which means the recycle HDPE is stiffer than the pure one. However, UTS for recycle HDPE is much lower than the pure which is 0.0264 GPa compare to the pure HDPE (7.60 to 43.0 GPa) and the yield strength for average recycle HDPE is 16.956 MPa. It is quite lower than the pure HDPE which is around 23.0 to 29.5 MPa. The result of the test help to understand the material quality. As for the hardness test the virgin HDPE exhibited a Shore D Durometer hardness around 55 to 67, whereas the recycle HDPE had a Durometer hardness of 41.4 to 43.6 only. After all, all of this result may affected form the main chain scissions accompanied by a decrease in the molecular weight which came from the possible degradation through the recycling process.

5.2 Recommendation

This study should be done with experimenting its chemical properties to know how it affected recycle HDPE. Nevertheless, HDPE properties can be further exploited by introducing organic or inorganic particles into the polymer matrix to strengthen its bonding and increase the tensile strength and hardness of recycle HDPE.

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